

Section 6

Hydrogeology and Hydrology

Hydrogeologic Framework

In 1997, a hydrogeologic investigation was completed at the site (EGS, 1997). The investigation consisted of drilling 44 soil (auger borings), performing laboratory tests to better define the properties of the soils and refine the visual classification of soils, and installation of 8 piezometers around the Lake Henrietta basin. The results of these investigations were used to supplement the published hydrogeologic data for the area.

Based on published and site specific information (Hendry and Sproul, 1966; Yurewicz and Rosenau, 1986; Pruitt et al., 1988; Scott et al., 1988; Davis, 1995) the hydrogeology of the site and the regional area is defined by three units:

1. A surficial aquifer which consists of sands and clayey sand, and is 10 to 50 feet thick. The aquifer characteristics of this water-bearing unit are assumed to be relatively uniform.
2. A middle unit (Hawthorn Group) which generally functions as a confining unit between the surficial and deeper Floridan aquifer, composed mostly of very low permeability clay and sandy clay, with occasional pockets of phosphatic limestone, and dolostone which are more permeable. These more permeable deposits are believed to be generally thin, discontinuous lenses and are known as the Intermediate aquifer. The Hawthorn Formation is 0 to 50 feet thick.
3. A deep layer consisting of 1,500 feet of marine limestone and dolostone representing the Floridan Aquifer System, which regionally serves as an important water supply source. The Floridan Aquifer System is also assumed to be characterized by relatively uniform aquifer characteristics.

A north south regional geologic cross-section through this part of Leon County is presented on **Figure 6-1**.

Physiography and Potential for Sinkhole Development

The Lake Henrietta basin and Munson Slough are located in the physiographic unit known as the Woodville Karst Plain (Hendry and Sproul, 1966). The Woodville Karst Plain is further subdivided into the Lake Munson Hills and the Wakulla Sand Hills. This area is characterized by a gently sloping topography with occasional hills reaching elevations of +80 to +100 feet NGVD. In the subsurface, clays and silts are mixed with sand resulting in a poorer permeability and more restricted downward percolation of groundwater with resulting less solution of the bedrock than is found within the eastern portion of the Woodville Karst Plain. A north-south physiographic cross-section through Leon County is presented on **Figure 6-2**.

The potential for sinkhole formation in northern and central Florida has been the subject of many reports and publications (Bureau of Geology, 1972; Jammal & Associates, 1982; Sinclair and Stewart, 1985; Wilson et al., 1987). The following discussion is based on a review of these publications and reports.

Sinkholes generally result from one of two types of processes. A less common type of formation activity is a collapse type sinkhole. Collapse type sinkholes result from the collapse of the roof of the cavities within the limestone formation followed by the subsequent subsidence of overlying unconsolidated material. Sinkholes resulting from collapse are generally steeply sided while those that result from raveling are more funnel shaped depressions that broaden outward. The most common sinkhole formation process is known as raveling, which is also known as a subsidence sinkhole. By far, the vast majority of sinkholes formed in northern and central Florida occurs in this manner.

Raveling sinkholes originate with bedrock formations containing openings or cavities at the upper surface of the formation. A raveling sinkhole initially develops slowly as soil from the overlying unconsolidated strata erodes into openings within the bedrock limestone. This continual erosion and raveling of the soil into the bedrock formation creates a dome shaped cavity within the overburden. Under favorable hydrogeologic conditions, the cavity enlarges until the dome can no longer support the overlying material, at which point collapse occurs. Within northern and central Florida, ravel type sinkholes are generally formed in an environment with the following characteristics:

- # Sedimentary formations (primarily limestone) containing openings that are overlain by unconsolidated sediments 150 feet thick or less.
- # Cavity systems with the sedimentary formation extending upwards and in contact with the overlying unconsolidated sediments.
- # A water table considerably higher than that of the potentiometric surface of the Intermediate and Floridan aquifer systems.
- # High Floridan aquifer recharge resulting from breaches in the aquitards overlying the Intermediate and Floridan aquifer systems.
- # Sufficiently large cavities, fractures or other openings within the sedimentary formation that can receive the eroded overlying unconsolidated material.

Under the above described conditions, water moving downward from the unconfined aquifer can transport large amounts of sediment into the cavernous limestone. This creates a void within the overlying sediments (usually the Hawthorn group formation). The areas within northern and central Florida where sinkhole formation is the most common, have limestone cavity systems at a depth of 50 to 150 feet below ground surface. Based on the results of the site-specific geotechnical investigation and published data, the top of the Intermediate aquifer system occurs at depths ranging from 0 to 25 feet below ground surface in the project area. However, this aquifer is extremely thin and is composed of sand, limestone and gravel. Therefore, surface expression of a sinkhole that forms in the Intermediate aquifer would not be as great as a sinkhole that forms within the Floridan aquifer system. Additionally, the top of the Floridan aquifer system occurs at depths ranging from 25 to 100 feet below ground surface at the site.

Certain topographic features including the presence of closed depressions, lakes, a lack of surface drainage systems, and areas of significant topographic relief are all indicators of sinkhole potential. A review of the USGS quadrangle survey map and observations made during site visits indicates that there are nine closed depressional areas located along the alignment of Munson Slough between Spring Hill Road and Lake Munson. Additionally, surface water drainage is very well defined. Stormwater runoff and surface water flows through Munson Slough to Lake Munson.

The relationship between the water table and the potentiometric surface is important in evaluating the sinkhole potential of a particular area. Large head differences across the aquitards that separate the surficial aquifer and Intermediate aquifer systems and the Intermediate aquifer and Floridan aquifer systems result in large downward vertical hydraulic gradients. If the vertical hydraulic conductivity is relatively high, the rate of vertical leakage is also high and the probability of sinkhole formation increases. Based on groundwater elevation readings in the onsite monitoring wells and piezometers, the head difference between the surficial and Upper Floridan aquifer systems ranges from 2 to 10 feet. These are relatively large head differences, however, the aquitard (Hawthorn Group) is thick (0 to 25 feet) and composed of low permeability clays (10^{-3} to 10^{-4} feet per day). According to the US Geological Survey (Scott, et. al, 1991), the site is located in an area of moderate to high recharge to the Floridan aquifer system.

Standard Penetration Test (SPT) borings that penetrate the Intermediate and Floridan aquifer systems can be used to indicate the presence of active raveling conditions. SPT borings that have frequent loss of circulation combined with low penetration resistance throughout significant reaches of the boring are considered indicators of potential active raveling. Typically, in the areas in which no ongoing raveling is occurring, there will be loss of drilling fluid and falling rods at the interface of the unconsolidated surficial sediments and the underlying limestone.

No SPT borings were drilled as part of the geotechnical investigation for Lake Henrietta. However, SPT borings will be drilled in the near future as part of the foundation analysis for the proposed control structures.

The Florida Geological Survey (Spencer and Lane, 1995) has published a sinkhole index for Florida based on data compiled by the Florida Sinkhole Research Institute. The database contains a listing for over 1900 sinkholes. From this database, a total of 37 sinkholes have been reported in Leon County. The closest sinkhole to the project area is located approximately 4,000 feet southeast of the confluence of the east drainage ditch with Munson Slough. The locations of the sinkholes in Leon County are shown on **Figure 6-3**.

Based on a review of published information and a comparison with site specific data, the probability of sinkhole formation in the project area is very low (**Figure 6-4**). Additionally, it is considered unlikely that the potential for sinkhole formation will increase due to maintenance activities in Munson Slough and Lake Henrietta. This portion of Leon County is characterized by limestones at or very near the land surface. Although the density of sinkholes is high, the intensity of surface collapse is moderate due to a lack of overburden.

Hydrological Monitoring Program

Groundwater

A total of 8 two-inch diameter PVC piezometers were installed in the surficial aquifer and shallow artesian aquifer around Lake Henrietta. Two of the piezometers were installed into the Upper Floridan aquifer at the site (PZ-1 and PZ-4). The piezometers were installed at the site to measure only groundwater levels in the surficial and Upper Floridan aquifers. The locations of the existing on-site piezometers are presented on **Figure 6-5**. Construction data for the piezometers are summarized in **Table 6-1**. Piezometer completion reports including the corresponding soil profiles for each piezometer are presented in **Appendix E**.

Depth to groundwater was measured eight times between June 10 and September 12, 1997 in the 8 piezometers installed within the site. The depth to groundwater was subtracted from the top of casing elevation to calculate groundwater elevations for each location. Groundwater elevation data collected for this project are presented in **Appendix F**. Groundwater elevations at PZ-1 through PZ-8 for the period June through August 1997 are shown on **Figure 6-6**, **Figure 6-7** and **Figure 6-8**.

From data on these figures groundwater elevations immediately adjacent to Lake Henrietta ranged from +29 feet NGVD to +32.5 feet NGVD. From the results of the groundwater level monitoring data, the normal seasonal high groundwater table in the vicinity of Lake Henrietta is estimated to be approximately +31 feet NGVD. As discussed later, the rainfall in July and August 1997 was very close to the long term average for Tallahassee.

Surface Water

The NFWFMD maintains a continuous stage recorder, designated as S-3, in Munson Slough at Capitol Circle as shown on Figure 5. Monthly average surface water elevations at the stage recorder for the 10 year period from 1987 through 1996 are presented in **Table 6-2**. Using the four month period from June to September to define the wet season, the normal seasonal high surface water elevation at this stage recorder is +29.5 feet NGVD. However, the proposed Lake Henrietta attenuation pond will be approximately 3000 feet upstream of the stage recorder. Using an average hydraulic gradient of approximately three feet per mile (the gradient between the stage recorder and Lake Munson, the resulting normal seasonal high surface water elevation in the vicinity of the attenuation pond would range from approximately +30 to + 31 feet NGVD.

Water elevations at S-3 for the period January through June 1997 are shown on **Figure 6-9**. Historical surface water elevation data collected for this project are presented in Appendix F.

Rainfall

Daily Rainfall is measured at the National Oceanic and Atmospheric Administration (NOAA) station at the Tallahassee Municipal Airport. The NFWFMD also maintains a dedicated rainfall gauge at Capitol Circle near Munson Slough. Monthly and annual NOAA rainfall totals data for the Tallahassee Municipal Airport for the period of record are presented in **Appendix G**.

Daily rainfall totals for the NOAA Tallahassee Station are shown along with the groundwater

elevation data on Figures 6 through 8 to show the response in piezometric surface with rainfall. Additionally, the NOAA rainfall totals for 1997 are compared with the NFWFMD daily rainfall data and surface water levels in Munson Slough at Capitol Circle, as shown on Figure 6-9. As indicated on Figure 6-9, the total rainfall for 1997 through August is very close to the long-term average for Tallahassee.

Conceptual Groundwater Flow System

Measured Groundwater Elevations. Based on data collected from June 1997 through August 1997, water table elevations in the vicinity of Lake Henrietta range from a high of +31 feet NGVD in the northeastern portion of the site to +28 feet NGVD in Munson Slough near Capitol Circle. The water table generally follows the topography and therefore, declines from east to west, causing the groundwater to flow in the same direction.

According to potentiometric surface maps for the Upper Floridan Aquifer (Scott et. al, 1991) flow is generally from the higher topographic areas (higher recharge) in the north towards the south. The potentiometric surface map for May 1989 indicates that locally the potentiometric surface elevation ranges from of +15 to +25 feet NGVD.

Conceptual Flow Model

The source of water to the surficial groundwater system in this area is recharge from rainfall. The direction of groundwater flow in the surficial aquifer is influenced by surface water features. Regionally, groundwater flow is from the uplands (Tallahassee Hills) toward the Gulf of Mexico. Locally, discharge from the surficial aquifer occurs at Munson Slough and Lake Munson and surrounding wetland areas. On site flow in the surficial aquifer is from the higher topographic areas in the east and west and discharges at Munson Slough. Groundwater flow in the surficial aquifer also has a vertical component which is generally downward through the Hawthorn Group Formation.

Groundwater flow through the Hawthorn unit is essentially vertically downward from the surficial aquifer, providing recharge to the Upper Floridan Aquifer. Vertical head differences in groundwater level can be as much as 2 to 10 feet across the Hawthorn Group. There is no significant horizontal flow in the Hawthorn. There is no significant pumping from the Intermediate aquifer in this area.

Groundwater flow in the Upper Floridan Aquifer is from north to south in this region. Sources of water to the upper Floridan in this area include horizontal flow and recharge through the Hawthorn.

Rainfall and Evapotranspiration

Rainfall and subsequent infiltration are the primary sources of freshwater that replenish the surficial aquifer system in northwest Florida. A relatively small percentage (<15 percent) of rainfall "runs off" to surface waters such as ditches, lakes, creeks, rivers, and swamps. In addition to runoff losses, a significant amount of water (>60 percent) is also lost to evaporation and transpiration (ET).

The National Oceanic and Atmospheric Administration (NOAA) maintains a dedicated weather station at the Tallahassee Municipal Airport. The average annual rainfall for the Tallahassee

Municipal Airport Station for the 46 year period of 1951 through 1996 was 63.33 inches. The annual rainfall totals and average monthly rainfall for the Tallahassee Municipal Airport Station for the period between 1951 and 1996 are presented in Appendix G.

Evapotranspiration (ET) is the process by which water is transferred to the atmosphere from vegetative surfaces. The amount of water transferred by ET is governed by a number of environmental factors. Minimal ET rates occur during dark, cloudy days, with high relative humidity, low temperatures, and no wind. ET rates are maximized on bright, sunny days, with low relative humidity, high temperatures, and moderate to high winds. Normally in Florida, the month of May has the highest ET rates because of these factors (Augustin, 1984).

In general, the majority of rainfall returns to the atmosphere as evaporation and transpiration. Evaporation typically occurs from open bodies of water such as lakes, streams, and rivers; however, open water bodies cover only a small percentage of the landscape within the project area. ET, which is a combined process of direct evaporation and transpiration, occurs from all vegetation and is the predominant mechanism for returning rainfall back to the atmosphere. ET values for cultivated crops throughout the United States are published in literature. In contrast, ET rates for undeveloped forested areas such as wetlands and upland forests are not well known.

Potential evapotranspiration (Et_p) is the rate at which water, if available, would be removed from the soil and plant surfaces by evaporation and transpiration. The concept of potential evapotranspiration implies that the plant canopy is actively growing and able to supply water to satisfy the climatic demand. The ET of wetlands typically approach the Et_p for an area.

The average ET for Tallahassee is 39.67 inches per year (USDA, 1982). According to the Institute of Food and Agricultural Sciences (Smajstrla, et. al., 1984) the Et_p for Tallahassee is 43.67 inches per year.

Conceptual Steady State Water Budget

The relationship between rainfall, ET, stormwater runoff and recharge in the overall site water budget is given below:

$$\text{Rainfall} = ET + \text{Stormwater Runoff} + \text{Recharge}$$

Based on data collected by NOAA, the average annual rainfall for Tallahassee is 63.3 inches per year. According to the SCS, the average annual ET Tallahassee is estimated to be approximately 39.7 inches per year. On an average annual basis, stormwater runoff accounts for approximately 17.0 inches of the remaining 23.6 inches. Therefore, approximately 6.6 inches are left to recharge the surficial aquifer in this part of south Leon County. It must be pointed out that the amount of stormwater runoff that occurs at a particular site on an average annual basis is a function of the number and intensity of storm events and the imperviousness of the site. The estimate of 17.0 inches is a representative average for all of the land uses in this part of southern Leon County and is confirmed by the calibration of the SWMM model developed for this project (Camp Dresser & McKee Inc., 1997).

The components of the average annual steady-state water budget is for the project area. For calculation purposes, 1 inch per year over the site area (415 acres) corresponds to 0.0048 cfs or 0.031 mgd.

The average annual surface water budget for the site is written as follows (all units are in inches per year over the site area):

$$SWI + SRO + BASE = SWO + \Delta S/t$$

Where inflows are:

$$\begin{aligned} SWI &= \text{Surface Water Inflow} = 602 \\ SRO &= \text{Stormwater Runoff} = 17 \\ BASE &= \text{Groundwater Baseflow} = 2 \end{aligned}$$

and outflows are:

$$\begin{aligned} SWO &= \text{Surface Water Outflow} = 621 \\ \Delta S/t &= \text{Change in Storage with Time} = 0 \end{aligned}$$

There are two surface water inflow locations to the project area; (1) flow in Munson Slough at Spring Hill Road and (2) flow into Munson Slough from the East Drainage Ditch. The combined surface water inflow at these two locations were estimated from measured flow data in Munson Slough at Capitol Circle. From the SWMM modeling, the drainage ditch contributes 28 percent of the surface water inflow and Munson Slough at Spring Hill Road contributes 72 percent of the surface water inflow.

Surface water discharge was monitored in Munson Slough at Capitol Circle (Station 02327017) using a continuous measured water level recorder by the U.S. Geological Survey between 1979 and 1983. Since 1983, the NFWMD has monitored surface water discharge at this gauging station (Station S-3). Based on the surface water discharge data, the average discharge at this station is approximately 30 cfs.

According to the Florida Geological Survey (Rumenik, 1988), the average annual stormwater runoff to streams in this part of Leon County ranges between 15 and 20 inches per year. The U.S. Geological Survey (Bush and Johnston, 1988) reports that average annual stormwater runoff to streams in this part of Leon County is approximately 17 inches per year. A value of 17 inches per year was used for stormwater runoff in this analysis. Groundwater baseflow to Munson Slough was (estimated using Darcy's equation) 2 inches per year.

Since surface water outflow equals the sum of the surface water inflows under steady state conditions ($\Delta S=0$), surface water outflow is equal to 48.3 inches per year. The surface water outflow point occurs where Munson Slough flows into Lake Munson.

Stormwater runoff from the site ends up in Munson Slough. There are several natural depressional areas (wetlands) located within the site. For small, low intensity storms, the runoff is stored in the depressions. For larger, high intensity storms or extended high rainfall periods, the volume of stormwater runoff exceeds the depressional storage and overflow to Munson Slough occurs.

The average annual groundwater budget for the surficial aquifer in the project area is as follows (all units are in inches per year over the site area):

$$RECH + GWI + SWR = GWO + LEAKAGE + BASE + \Delta S$$

Where inflows are:

RECH	=	Recharge = 6.6
GWI	=	Lateral Groundwater Inflow = 2.0
SWR	=	Surface Water Recharge = 0

and outflows are:

GWO	=	Lateral Groundwater Outflow = 0
LEAKAGE	=	Vertical Leakage = 6.6
BASE	=	Baseflow to Surface Water = 2.0
ΔS	=	Change in Storage = 0

Lateral groundwater inflow to the surficial aquifer was (estimated using Darcy's equation) approximately 2.0 inches per year (normalized over the project study area). There is no lateral groundwater outflow from the project area in the surficial aquifer since Munson Slough and Lake Henrietta are a sink for shallow groundwater. Recharge in the uplands surrounding Munson Slough drives the groundwater flow in the surficial aquifer.

Vertical leakage from the surficial aquifer to the Floridan aquifer is estimated to be on the order of 6.6 inches per year. The hydraulic gradient is vertically downward throughout most of the project area and the Hawthorn Group sediments tend to be relatively thin. Vertical leakage accounts for about half of the surficial aquifer recharge.

The surface water features (lakes, creeks and rivers) do not contribute water to (recharge) the surficial aquifer. The surface water features are typically relief points for the surficial aquifer and receive about one-third of the recharge as baseflow from the surficial aquifer.

By subtraction, baseflow is calculated to be 2 inches per year. Baseflow is common to the groundwater budget and the surface water budget. The terms are internally consistent between the groundwater budget and surface water budget. Additionally, stormwater runoff and surficial aquifer recharge in the overall site water budget are internally consistent with the same terms in the surface water and groundwater budgets, respectively. Total groundwater outflow from the site (8.6 inches per year) is a relatively small percentage (1 percent) of the total outflow from the site. Conversely, surface water outflow (621 inches per year) is the largest outflow composing approximately 99 percent of the total outflow from the site.